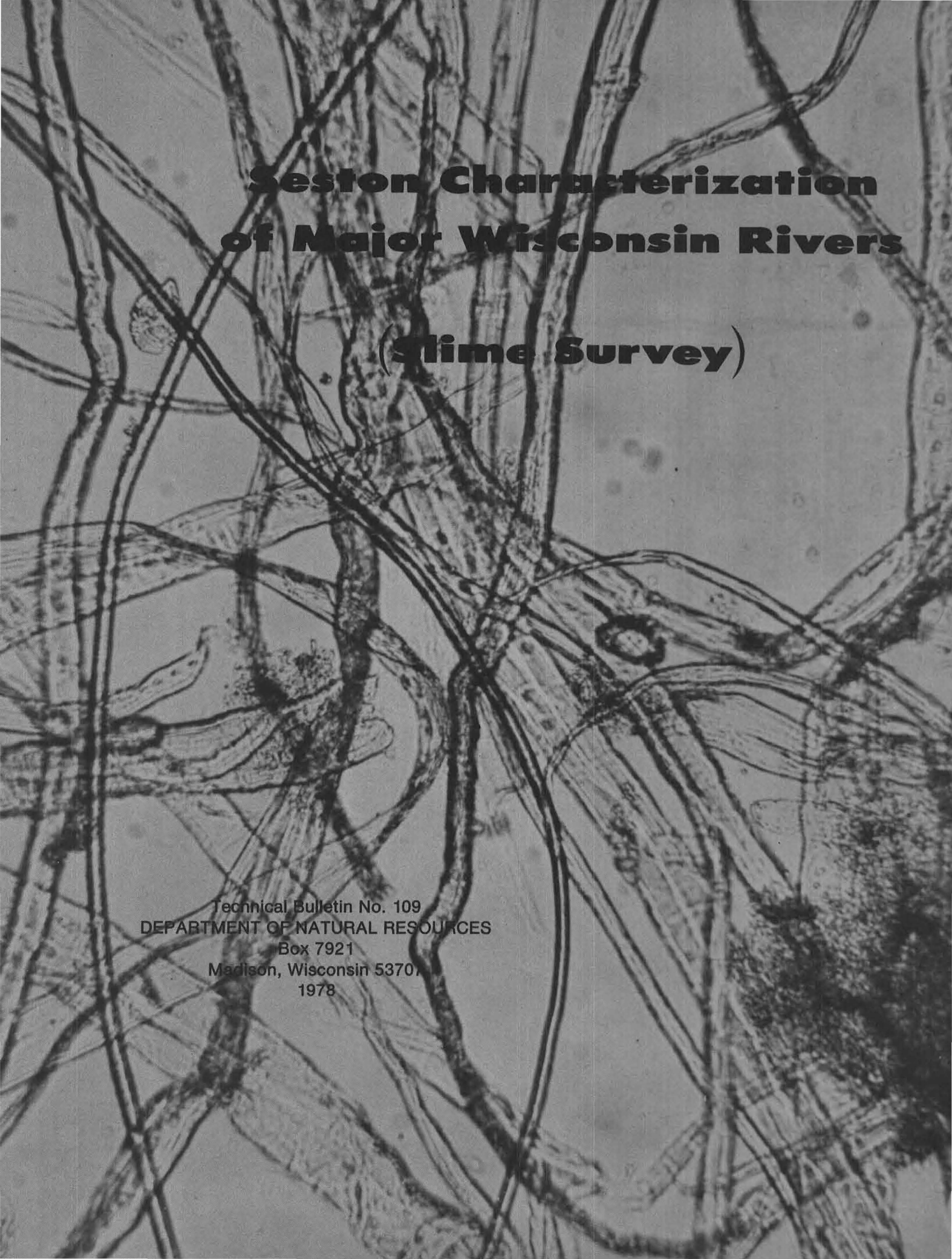

Seston Characterization of Major Wisconsin Rivers

(Slime Survey)

Technical Bulletin No. 109
DEPARTMENT OF NATURAL RESOURCES
Box 7921
Madison, Wisconsin 53707
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ABSTRACT

This study was conducted to assess the impact of paper mill discharges on the seston and periphyton characteristics of major Wisconsin streams, and to characterize the seston in other major streams. A similar study was conducted in 1963 to 1965 and the data are compared to assess improvements in water quality attributed to improved waste treatment.

Most paper mill discharges were found to be contributing to nuisance conditions in the forms of suspended and attached filamentous bacterial growths, and suspended wood fibers. Nuisance conditions were less severe below all but eight discharges compared to the 1963 to 1965 study. The seston of major drainage streams was dominated by natural organic debris, zooplankton, Microcystis and Melosira. The seston of smaller recreationally important streams was dominated by natural organic debris and silt.

Improved waste treatment has resulted in a reduction in nuisance slime and suspended wood fiber loads in most pulp and paper mill impacted streams.

SESTON CHARACTERIZATION OF MAJOR WISCONSIN RIVERS

(SLIME SURVEY)

By

Joseph R. Ball and David W. Marshall

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INTRODUCTION

In a 1963-65 study of seston loads in streams receiving paper mill effluents, the Wisconsin Committee on Water Pollution found that paper mill wastes contributed significantly to the development of nuisance conditions in receiving streams (Lueschow 1966). The nuisance conditions were identified as algae, filamentous bacterial slimes and suspended solids. High concentrations of algae are generally not a problem in streams; however, populations can reach nuisance levels in excessively rich low velocity and impounded streams. Filamentous bacterial slime growths can reach problem concentrations below some effluents containing specific nutrients, and waste water discharges high in suspended solids can create severe aesthetic and ecological problems. Generally, slime growths and suspended solids are immediate ramifications of waste water discharges, while algal production is stimulated by the nutrient increase farther downstream.

Excessive slime growth and suspended solids are usually traceable to specific discharges. Nuisance concentrations of algae are usually the result of high fertilization from various sources such as runoff, endemic fertility or point source discharges, and are more difficult to trace. These conditions individually and collectively contribute to stream degradation. Respiration of massive slime growths, and the biological oxygen demand exerted by the decay of slimes, algae and organic solids reduce dissolved oxygen concentrations. Desirable habitat is destroyed by the precipitation of suspended solids and decaying organic material, and the growth of attached algae and filamentous bacteria.

The present study (1976-77) was initiated to determine if the nuisance conditions previously identified still persist and to characterize the seston composition of other major streams for comparison and background data. The study is also a means of biologically and physically evaluating the effectiveness of Wisconsin's waste water control programs over the past few years.

ECOLOGY OF SLIME GROWTHS

One of the most significant effects of waste water discharges is the development of an ecologically dominant "sewage fungus" community. As the name suggests, the community consists of organisms that grow as a fungus-like slime below a specific discharge site. Most of the organisms are taxonomically unrelated, represented by fungi, bacteria and protozoans. All potential slime organisms are present in natural stream ecosystems; however, they are inconspicuous until stimulated to nuisance proportions by a specific nutrient source. The only major slime growth which is a true fungus is *Leptomitus Lacteus* or sometimes classified as *Apodya lactea*. The other important constituents of the "sewage fungus" community include: *Sphaerotilus natans*, a filamentous bacterium; *Zoogloea ramizera*, a bacterium that grows as an irregular mass of branching mucilage with cells arranged indiscriminately and at least two stalked protozoa. *Sphaerotilus* is typically the dominant "slime infestation" and deserves special attention here.

The nutritional requirements of *Sphaerotilus* include mono- and disaccarides which function as the major carbon source. Organic acids, alcohols, and amino acids are additional carbon sources. The nitrogen supply is furnished by amino acids and to a lesser degree, nitrates and ammonia. Sewage treatment, milk processing, and paper mill wastes stimulate production of slime growths by supplying growth requirements.

Most investigators agree that *Sphaerotilus* prefers a pH above 6.0 but not over 8.0. It grows well under a wide range of temperatures anywhere from 3° to 35°C. It flourishes during the colder months probably because of the lack of competition for nutrients and space from other organisms. *Sphaerotilus* is an obligate aerobe but can grow at very low dissolved oxygen concentrations. It is found growing only where there is sufficient flow. Flowing water provides a fresh supply of oxygen and nutrients as well as support for the filaments in the column of water. Generally, faster currents extend the zone of luxurious growths farther downstream. Flow may also have an effect on the rate of slime detachment and deposition.

Sphaerotilus usually grows attached to the substrate with one of the older cells acting as a basal holdfast. Sloughing free occurs when older cells die or the weight of the colony is too heavy to support. Consequently, *Sphaerotilus* becomes a significant part of the seston.

The most obvious effect of slime growths is an aesthetically unpleasant environment. Stream substrates may become completely covered eliminating habitat normally available for beneficial bottom-dwelling organisms and fish. Fishermen are plagued by the slimes as detached colonies float downstream. Where the current slows, slimes and suspended wastes settle out forming sludge deposits. The most significant effect of slime accumulation is on dissolved oxygen. The respiration of active growths consumes oxygen but more important is the BOD produced by the sloughed off decaying material. This effect may be exerted for some distance downstream from active slime communities.

METHODS

SESTON SAMPLING

Samples for seston and nutrient analysis were collected from 18 Wisconsin rivers for this study. The seston composition was identified and enumerated to characterize each stream or a particular stream segment. Ten of the rivers were sampled to provide biological background data, and for a comparison to streams receiving waste water effluents. The other 8 rivers were sampled specifically to update the 1966 Slime Survey and emphasis was placed on this part of the study. Table 1 lists the rivers surveyed and the number of sample stations established on each one. Figure 1 shows the locations of these rivers within the state.

Quantitative sampling of seston can be accomplished by various procedures which are well known. However, seston sampling of streams in sufficient volume to insure representative interpretation presents some problems. Shallow water at many sites makes net towing impossible and grab sampling does not generally produce a high enough volume of material for the analytical techniques used for this study. An important part of this survey was winter sampling under the ice which again eliminates net towing as a procedure. For these reasons a metered pump was used for sampling (Fig. 2). A 1¼ horsepower pump with a flowmeter attached to the outlet was used. Samples were collected by pumping water at low velocity through a standard #20 (80 um) mesh plankton net with cup attached. No specific quantity of water was filtered, but enough to provide what appeared to be a sufficient concentration of seston for analysis. The volume of water pumped varied from 40 to 7,750 liters, depending on the amount of suspended material. All samples were collected from a depth of 1 m except where the water was not that deep. Use of the pump enabled sampling from a boat, from the shore or from holes drilled through the ice.

When sampling from a boat the net was held over the side in the water. Pumping into the water in the net reduced the turbulence and pressure exerted on the net thus reducing the loss of material through the net. Care was taken to place the intake upstream from the filtered outlet. When sampling from shore the intake was supported by a rod driven into the bank or river bed to keep it off the bottom. A 10-gallon galvanized garbage can was filled with water and then the net was hung in the water for filtering. Sampling under ice cover was accomplished by drilling two holes, one upstream and one downstream. The samples were filtered by pumping through the net in the downstream hole. The holes were

TABLE 1. *Rivers surveyed and number of sampling stations*

River	Total sampling stations
1. Wisconsin River	42
2. Lower Fox River	56
3. Chippewa River	15
4. Flambeau River	12
5. Wolf River	7
6. Menominee River	10
7. Oconto River	5
8. Peshtigo River	4
9. Rock River	6
10. Fox-Illinois River	4
11. Black River	4
12. Platte River	3
13. Bois Brule River	1
14. Pike River	1
15. St. Croix River	3
16. Mississippi River	9
17. Badfish Creek	2
18. Sugar River	4
Total sample stations	188

drilled approximately 7.5 m apart. All samples were transferred to glass bottles and preserved with 4% formalin.

The only difficulty encountered with these procedures was when the water was shallow the pump could suck sediment from the bottom. One meter was damaged when this occurred. Shallow sampling sites had to be relocated. When the sampling procedure was iniatiated there was concern that the more delicate organisms may be damaged in passing through the pump. A comparison was made of organisms collected by a hand-pulled net and the pump, and no difference was observed in condition of the organisms.

OTHER PARAMETERS

(1) Secchi depth measurements were taken as another measurement of the relationship between upstream and downstream point sources. Because of the current at many stations a calibrated rope could not be used. The secchi disc was attached to a 2 m aluminum pole to prevent the disc from floating away from the vertical. In some cases secchi readings could not be taken because of shallow water.

(2) Nutrients — samples were taken at most stations to determine nutrient loading or for background data. Parameters included total and soluble phosphorus, total organic nitrogen, ammonia, and nitrate plus nitrite. The value of these parameters are significant when determining nutrient inputs which stimulate primary growths. All samples were collected just under the surface. After collection all samples were iced and mailed to the laboratory in styrofoam containers. All analyses were completed with 24 hours of the collection time.

(3) Observations — quantitative periphyton and benthic sampling were not included in this study although they are important indicators of water quality. At each sampling station observations were made to determine the presence or absence of such things as attached forms of algae and slimes and their relative abundance. Slime samples were taken for identification. Field notes were also taken on the location of sludge banks, wood chip and fiber deposits and general habitat deterioration.

SAMPLE ANALYSIS

Seston analysis was based on percent composition by volume of the various components, total solids, and to-

FIGURE 1. *Locations of rivers sampled.*

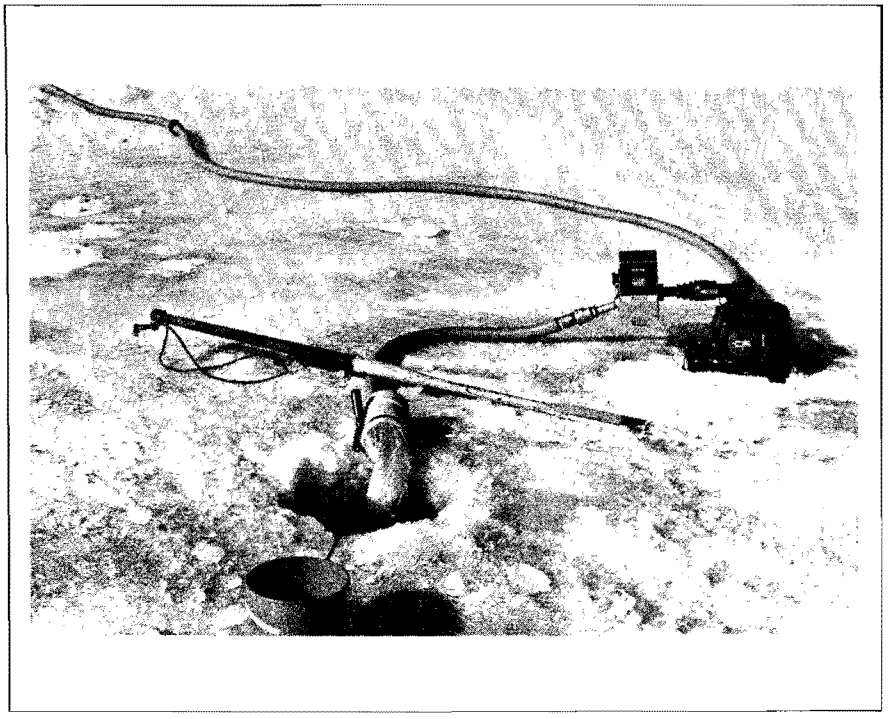


FIGURE 2. *Pump and plankton net used to obtain seston samples.*

tal volatile solids expressed in ug/l. Eight major categories were identified: algae, diatoms, zooplankton, protozoans, paper fibers, slimes, organic debris, and silt. Percent composition was determined by transferring 2 ml of mixed sample to a petri dish, allowing it to settle and examining microscopically. The percent composition of the various organisms and other components was then estimated by at least two and sometimes three biologists. The organisms were identified to genus, but only the most abundant genera were listed as separate categories. The results were then averaged and tablulated. This procedure was used in the previous study and in other plankton studies in Wisconsin, and when compared to more detailed analysis the water quality interpretation has been comparable. Seston composition in waste-water-affected samples is generally dominated by two or three categories and these are assigned a high percentage. Samples with a wide variety of organisms were generally found at stations with fair water quality. Estimation of percent composition was difficult in these situations, but all genera observed were listed and assigned estimated values. In many cases it was necessary to slide-mount specimens and identify them under a compound microscope.

When the estimation of percent composition and identification was completed, the contents of the petri dish were returned to the bottle, and the whole sample was analyzed for total and volatile solids by standard methods.

All solids and nutrient analyses were performed at the Wisconsin State Laboratory of Hygiene by the following procedures:

(1) Total solids[1] — gravimetric determination of material remaining after evaporation and drying under standardized conditions.

(2) Volatile solids[1] — the residue from the total determination is subjected to a temperature of 550°C for 30 minutes, then partially air cooled, desiccated and weighed. The loss in weight represents volatile or organic matter.

(3) Total Phosphorus[2] — all the phosphorus present in the sample, regardless of form, extracted by persulfate digestion and measured colormetrically.

(4) Soluble Reactive Phosphorus[2] — ammonium molybdate and potassium antimonyl tartrate react with orthophosphate to form phosphomolybdic acid which is reduced to molybdenum blue by ascorbic acid and then read colormetrically.

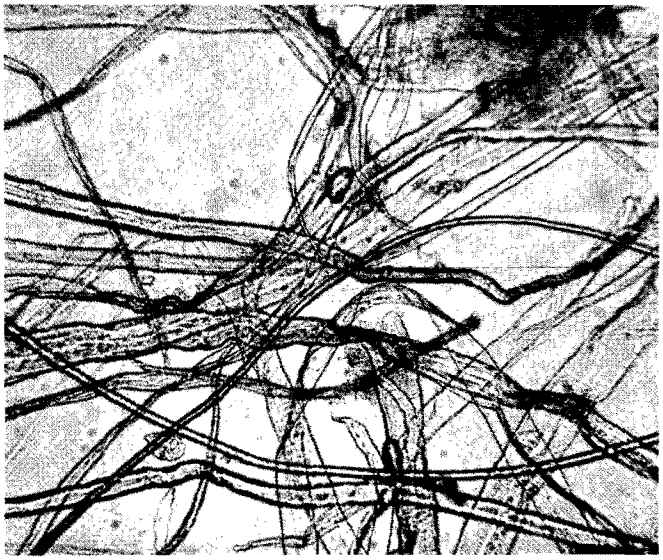
(5) Organic Nitrogen[1] — sulfuric acid digestion after removal of free ammonia, with subsequent distillation and determination of liberated ammonia.

(6) Ammonia[2] — automated colorimetric phenate method — A.A.II.

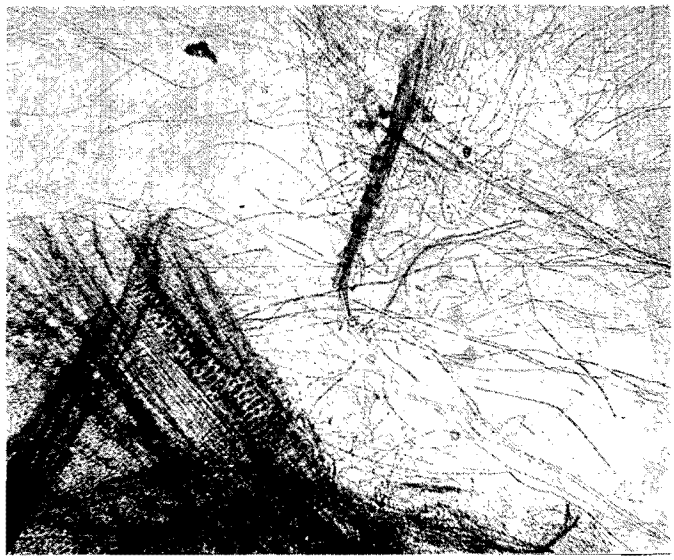
(7) Nitrate and Nitrite[2] — automated colorimetric method — A.A.II.

[1]Standard Methods, 13 ed.

[2]EPA. 1974. Methods for chemical analysis of water and waste.



Wood fibers.



Wood fibers and filamentous bacteria (right).

RESULTS AND DISCUSSION[3]

SESTON COMPOSITION

Wisconsin River

Station 1 was established above Rhinelander at McNaughton (Fig. 3). Only a few small communities discharge treated wastes into this section of the river. Samples collected during May, August and February revealed total solids concentrations of 338, 436, and 93 mg/l respectively. The seston characteristics and nutrient concentrations were typical of a relatively clean stream.

Stations 2 and 3 were established below the St. Regis Paper Company in Rhinelander. Total solids concentrations were higher than Station 1 concentrations during all sampling periods, and more than 50% of the seston was composed of paper fibers and *Sphaerotilus*. The river is grossly discolored and slime growths and suspended solids are obvious in this area. Station 6 was established below Hat Rapids Dam 9.7 km (6 miles) below St. Regis Paper Company. Total solids concentrations were lower but paper fibers and slimes were present in the May and February samples. Samples taken adjacent to Ski Hill Road, 13.8 km (8.6 miles) below the mill, were generally higher in solids which is attributed to debris in May, plankton in August, and slime in February. The periphyton from Rhinelander to this point was dominated by *Sphaerotilus* and *Cladophora*. Station 8 was located at County A bridge 28.2 km (17.5 miles) below Rhinelander. Total solids were consistently low at this station. Slimes were not observed, although they did contribute to 40% of the seston load during the February survey. The data indicate that the St. Regis Paper Company discharge contributes to nuisance conditions extending at least to the Hat Rapids Dam. Most of the discharged paper fibers tended to settle out in the impoundment above Hat Rapids Dam. Below this point, and extending to Lake Alice, nuisance conditions (slimes and filamentous algae) may develop depending on other influences such as flow and water temperature.

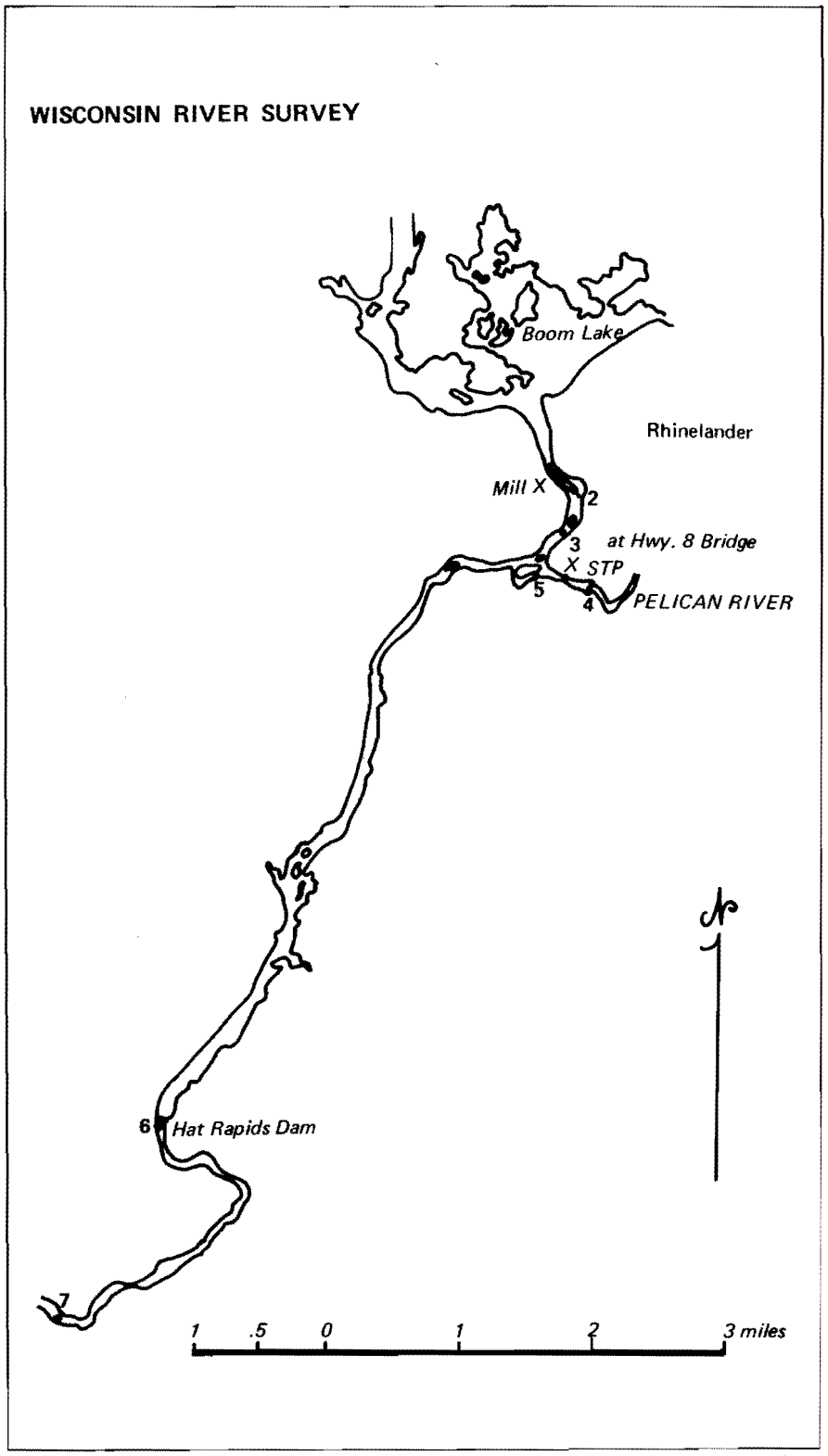
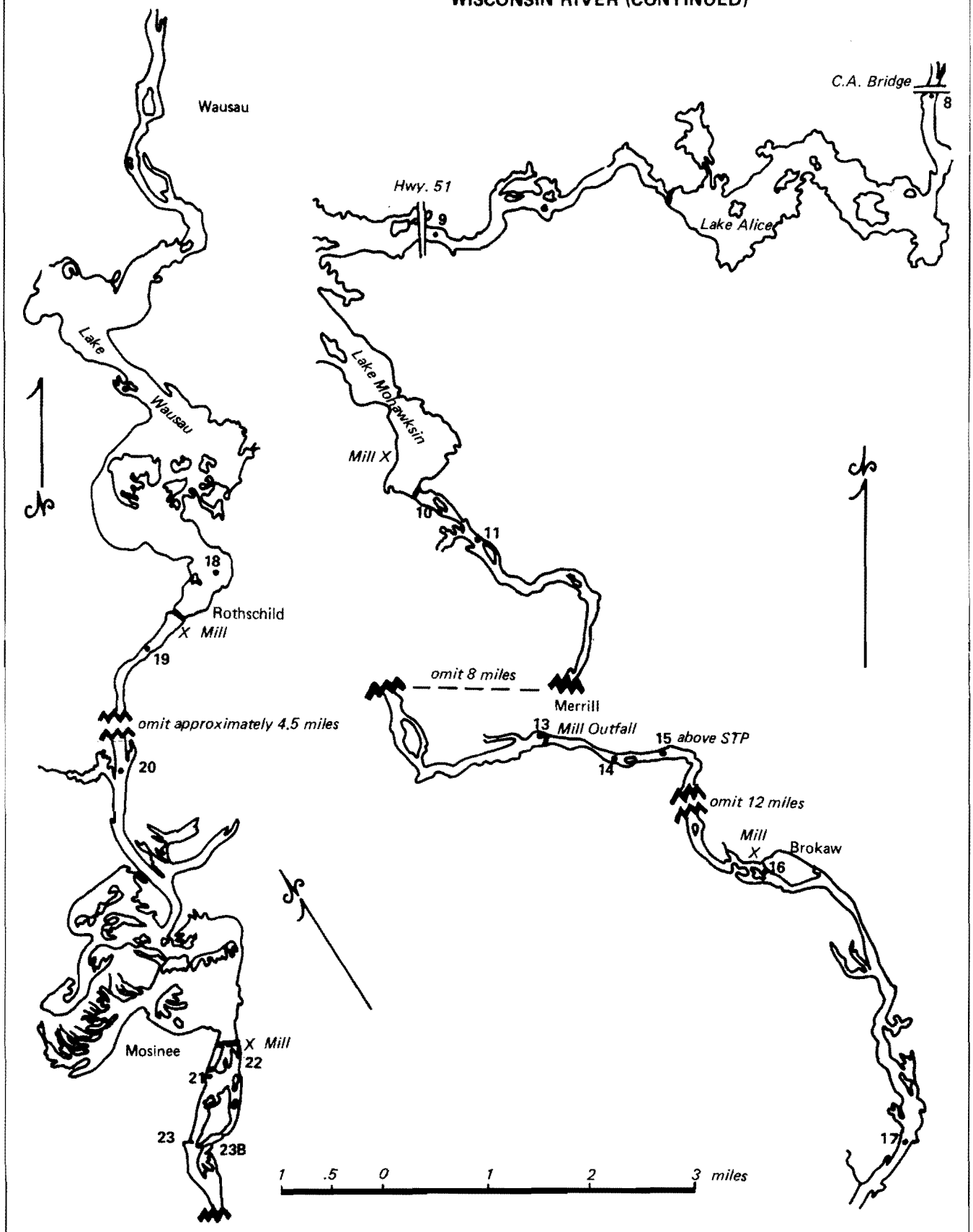
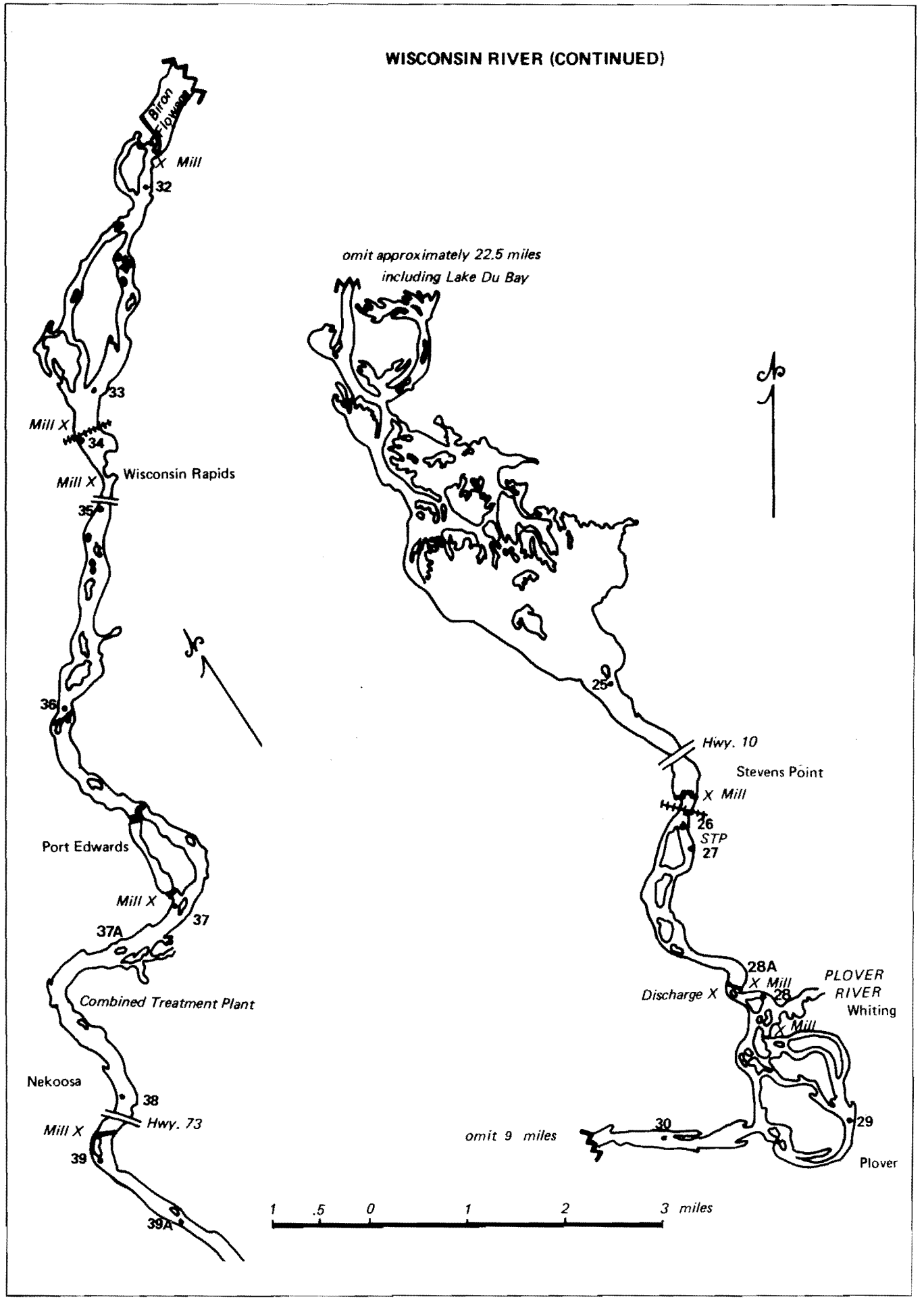


FIGURE 3. *Location of sampling stations along the Wisconsin River.*

[3] Detailed quantitative summaries of the nutrients and seston composition of the 18 rivers sampled (Table 1) are presented in an Appendix, published in limited quantity under separate cover. The Appendix is available in document library copies of Technical Bulletin No. 109, and from the Department of Natural Resources, Bureau of Water Quality, Madison, WI.

WISCONSIN RIVER (CONTINUED)




WISCONSIN RIVER (CONTINUED)
Biron Flowage
X Mill
32
omit approximately 22.5 miles
including Lake Du Bay
33
Mill X
34
Mill X
Wisconsin Rapids
35
36
Port Edwards
Mill X
37
37A
Combined Treatment Plant
Nekoosa
38
Mill X
Hwy. 73
39
39A
omit 9 miles
30
29
Plover
1 .5 0 1 2 3 miles
25
Hwy. 10
Stevens Point
X Mill
26
STP
27
28A
X Mill
Discharge X
28
PLOVER
RIVER
Whiting
X Mill

Additional samples were collected in February above and below the Rhinelander sewage treatment plant (STP) on the Pelican River. Total solids were 188 ug/l compared to 12 ug/l above the STP. Approximately 70% of the below sample was composed of paper fibers which indicates that the plant is receiving waste from a paper-making or handling industry.

Station 9 was established near the Highway 51 bridge in Tomahawk, 4.5 km (2.8 miles) below Tomahawk Power and Pulp Company. Total solids analysis of the May, August and February samples revealed 35, 748, and 29 ug/l respectively. The high concentration in August was composed of phytoplankton and zooplankton and is expected at that time. Fibers and slimes were not evident in May and August, but the February sample contained 37% paper fibers and 8% slimes. This sample was collected from a depth of 2m, as opposed to the general procedure of collecting samples near the surface, indicating that the fibers settle out rapidly and are carried along the bottom in slower currents.

Station 10 was located below the Owens-Illinois, Inc. mill and Lake Mohawksin dam near Tomahawk. Paper mill wastes were insignificant on all three sampling dates; however, evaluation of the Febraury sample revealed a 40% slime composition. Slimes were also observed below the dam attached to rocks and in suspension. Station 12 was established above the Grandfather Dam, 19.5 km (12.1 miles) below the Lake Mohawksin dam. Solids concentrations were reduced and only a trace of slime was observed in the August seston sample.

Effluent from the Ward Paper Company discharges to the Wisconsin River in Merrill. The river is swift in this area and causes the effluent to channelize along the north shore. The May and August samples were not considered representative because of the channelizing effect, although traces of fibers and slimes were found. In March a sample was collected 20 m below the outfall near the north shore. The total solids concentration increased from 19 ug/l above the outfall to 183 ug/l below. The seston composition was 50% paper fibers, attached slime growths were noted, and water clarity was decreased. Sample number 15 was collected in February just above the Merrill STP, 1.6 km (1 mile) below Ward Paper Company. Total solids were still relatively high at 89 ug/l and paper fibers accounted for 25% of the seston. Below this point the paper mill wastes became mixed with the entire flow and were not evident.

Station 16 was established 100 m below the outfall of Wausau Paper Mill Company, Brokaw. Total solids concentration in May, August and February were 1,292, 1,273, and 877 ug/l, respectively. The seston was dominated by paper fibers and slimes in all samples. In addition, attached slime growths were extensive and dominated by *Leptomitus*, nutrient concentrations were extremely elevated, and water clarity was greatly reduced. Extensive sludge deposits were also noted. Station 17 was established 4.8 km (3 miles) below Wausau Paper. Total solids were decreased, but paper fibers and slime growths were still significant in each sample. Station 18 was located just upstream from the Highway 29 bridge, 8.8 km (5.5 miles) below Brokaw. Nuisance conditions were not generally observed although total solids were 175 ug/l in August. The presence of slimes in August, and a trace of paper fibers in the winter samples indicate that the Wausau Paper Mill still affects the stream at this point.

Station 19 was established between the Weyerhaeuser Paper Company and Rothschild STP outfalls. Analysis of May, August and February samples revealed total solids of 396, 139, and 57 ug/l. The August concentration of 139 ug/l was slightly lower than the upstream concentration. The lower value is attributed to a reduced concentration of paper fibers (2%, compared to 15% in May and February). Solids concentrations at this site were not extremely high, but filamentous bacteria and paper fibers accounted for a major percentage of the seston. In addition, the river was covered with a dense layer of foam and attached slimes were noted near the east shore. Station 20 was established at Happy Hollow, 8.5 km (5.3 miles) below Weyerhaeuser. Solids concentrations were generally reduced from the previous sample but slimes and paper fibers were still found in the seston, and floating and attached slimes were abundant.

The Mosinee Dam and Mosinee Paper Corporation are located 6.3 km (3.9 miles) below Station 20. Station 21 was established below the dam, in the west channel, which is not affected by the mill discharge. Total solids concentrations were generally higher than those at Station 20 due to increased production in the impoundment. The presence of slimes and paper fibers indicate that this area is still influenced by upstream paper mills. Stations 22, 23 and 23B were established below Mosinee Paper Corporation. The mill discharge appeared to be at a low volume during each visit and only the winter sample indicated a high solids concentration (1056 ug/l) directly below the mill. However, paper fibers and slimes dominated the seston in each sample. In addition, total organic nitrogen and ammonia were high in both the August and February samples. Station 23 located 1.6 km (1 mile) below the mill revealed generally lower solids and nutrient concentrations, but slimes and paper fibers still dominated the suspended material. Observations made up to 3.2 km (2 miles) below the mill indicated extensive anaerobic sludge deposits and growths of attached slimes. During the August survey many dead walleyes were observed below the mill. A portion of the data and field observations indicate the Mosinee Mill has a severe physical and chemical impact on the river for at least 3.2 km.

Approximately 7.7 km (4.8 miles) below Mosinee the Wisconsin River spreads out into Lake DuBay. Lake DuBay is 11.5 km (7.1 miles) long and the Big and Little Eau Pleine Rivers enter it from the west. Samples collected below the dam did not contain paper fibers, but slime growths were present in the May and February samples. The paper fibers apparently settle out in the impoundment but are probably subject to flushing during periods of high flow. Nutrient concentrations are high, and a total solids concentration of 1,824 ug/l, dominated by zooplankton and bluegreen algae, was found in August.

Station 25 was established at Bukolt Park above the Consolidated Dam in Stevens Point. Solids concentrations were not relatively high for an impoundment, but paper fibers and bacterial growths were found. The May sample contained a trace of filamentous bacteria and the February seston sample contained 10% paper fibers and 50% bacterial consortium. A bacterial consortium is a variety of filamentous bacteria embedded in a mass of extracellular mucilaginous material. This station is 37.5 km (23.3 miles) below the nearest paper mill outfall. Station 26 was established below the Stevens Point division of Consolidated Papers. Total solids concentrations were not elevated although paper fibers and slimes were present in all samples. An oil slick was associated with the effluent during the August survey. Station 27 was established directly below the Stevens Point STP in February. Total phosporus and solids concentrations (1,769 ug/l) were high. Biological floc made up 70% of the solids. The Stevens Point STP appears to have a much greater impact on the river than Consolidated Papers.

Station 28 was established just above the mouth of the Plover River, below Consolidated Papers Wisconsin River Division, near Whiting. In May and August total solids and percent composition of fibers and slimes were

relatively low. An obvious oil slick was associated with the effluent. The effluent from this mill enters the river above the dam and in February the sample was taken at that location. The solids concentration was relatively high (164 ug/l) and contained 65% paper fibers. It appears that most of the fibers settle out above the dam in normal and low flow periods. The high phosphorous concentration found in February is most likely from the Stevens Point STP discharge.

The Whiting-Plover Division Mill of Nekoosa Papers is located a short distance below the mouth of the Plover River. Below the mill the river splits up into a series of smaller channels and meanders through a marshy wooded area. The physical characteristics of the river in this area makes the assessment of a point source impact difficult. Sample station 29 was located in the east channel 2.2 km (1.4 miles) below the mill. This station was only sampled in August. A relatively high solids concentration was found, but 54% was composed of natural organic debris. A 4% paper fiber concentration and a trace of slime growth was found, but this area did not appear to be severely impacted by the mill discharge. Station 30 was located adjacent to Plover Park 3.4 km (2.1 miles) below the Whiting-Plover Mill. This site was sampled in August and February and nuisance conditions were not observed. The February sample revealed 25% fibers and 13% slimes; however, the solids concentration was only 15 ug/l. The fiber source may be a combination of the Consolidated and Whiting-Plover Mills.

Stations 32 and 33 were established below the Biron Division of Consolidated Papers. A slight increase in total solids and fiber concentration was noted at Station 32. A few attached slimes were also observed, but this effluent appears relatively clean and to have a minor physical impact on the stream.

Station 34 was located below the Kraft Division of Consolidated Papers at the railroad bridge in Wisconsin Rapids. This station was sampled only in February and a detrimental impact was indicated at that time. The concentration of total solids increased from 10 to 531 ug/l and was composed primarily of fibers, slimes and biological floc. A secchi disk reading of only 12.5 cm (5 inches) was obtained.

Station 35 was established at the Grand Avenue bridge below Consolidated Papers in Wisconsin Rapids. This site was sampled on three occasions and seston evaluation determined fibers and slimes to be significant. The August sample revealed a solids concentration of 400 ug/l. In addition, the periphyton consisted of obvious growths of filamentous algae and *Sphaerotilus*. Total organic nitrogen concentrations were elevated in the August and February samples. Station 36 was located above the Centralia Dam 3.8 km (2.4 miles) below the Consolidated Mill in Wisconsin Rapids. The May sample contained a 1,768 ug/l total solids concentration composed of 20% fibers and 5% slimes. Attached slimes and filamentous algal growths were obvious. The August sample did not reveal severe nuisance conditions. It appears that the fiber load tends to settle out above the dam in low flow periods.

The Nekoosa Papers, Inc. Mills are located at Port Edwards and Nekoosa, and are the southern most mills on the Wisconsin River. Station 37 and 37A were established below Port Edwards. The May sample at station 37 contained a solids concentration of 508 ug/l with 40% fibers. Attached and floating slimes were abundant. Total solids and fibers were not as significant in August due to the diverting of the effluent to a combined treatment plant serving the Port Edwards and Nekoosa Mills. Observations 2.2 km (1.4 miles) below the mill indicated heavy attached slimes and septic sludge deposits. This indicates the severe impact this mill has had. The improved waste treatment recently initiated will hopefully improve this stretch of the river.

Station 39A was established at the boat landing 1.2 km (0.7 miles) below the Nekoosa Mill outfall. The May sample revealed a solids concentration of 2,383 ug/l containing 80% fibers and 7% slimes. Observations indicated that heavy fiber concentrations persisted into the upper reaches of the Petenwell Flowage before settling out. Massive slime growths were also noted along the shores attached to exposed substrates. The concentration of total phosphorus, organic nitrogen and ammonia was also elevated below this mill on all three sampling periods. Following the diversion of effluent from this mill to the combined treatment plant, solids and fiber concentrations decreased significantly. The aesthetic improvement is substantial and the gradual improvement of downstream water quality may be anticipated.

The Wisconsin River enters Petenwell Flowage 9.6 km (6 miles) below the Nekoosa Paper Mill. Station 40 was established near Wilderness Park which is about half way down the flowage. Petenwell is a eutrophic body of water exhibiting dense algal blooms in summer and periodic low dissolved oxygen concentrations, especially under ice cover. The August survey total solids concentration was 2,906 ug/l dominated by the bluegreen algae *Microcystis*. Paper fibers were not observed but may have been masked by the algae. Samples collected in May and February were not comparatively high in solids, but did contain 4 to 10% paper fibers.

Lower Fox River

Twenty-seven sample stations were established from Lake Winnebago to Green Bay (Fig. 4) and sampled during June and August 1976, and January to March 1977. The current station locations are near the station locations for the 1966 study. Many stations were sampled in transect to determine the channeling effect of wastes traceable to point sources.

Stations 1 and 2 were established above the Neenah-Menasha Channel dams. During the August survey, total solids concentrations up to 1,612 ug/l were recorded from the Menasha (North) Channel. Heavy plankton growth is characteristic of Lake Winnebago during the summer months and sometimes made it difficult to determine the effect of waste sources on productivity.

The headwaters of the Fox River present a difficult point source assessment because of the number and variety of discharges in the area. The Neenah (south) Channel receives effluent from Kimberly-Clark Neenah Papers and Bergstrom Paper Company. Transect 3 was established at the mouth of the channel and stations 3s and 4 were located below the Bergstrom Paper outfall. Samples 3n and 3c indicate some influence from the Kimberly-Clark Mill with a slight increase in solids and a trace of fibers and slimes. Samples 3s and 4 indicate a severe impact from the Bergstrom Paper discharge. Samples from this area revealed significant increases in solids, paper fibers and slime growths. The water was grossly discolored and the secchi depth was less than half of the above stations. Bergstrom's effluent channelizes along the west shore and the color change can be traced the length of Little Lake Butte des Morts. In August under low flow conditions the effluent appeared to disperse from the point of discharge and affect the color of the entire lake. The percent composition of fibers and slime organisms was highest during the January survey.

Station 5 was located below the Kimberly-Clark Lake View Mill. This area is still influenced by the Bergstrom discharge, making point source evaluation difficult. Sample analysis and observations did not indicate a significant influence on water quality from the Kimberly-Clark Mill. While

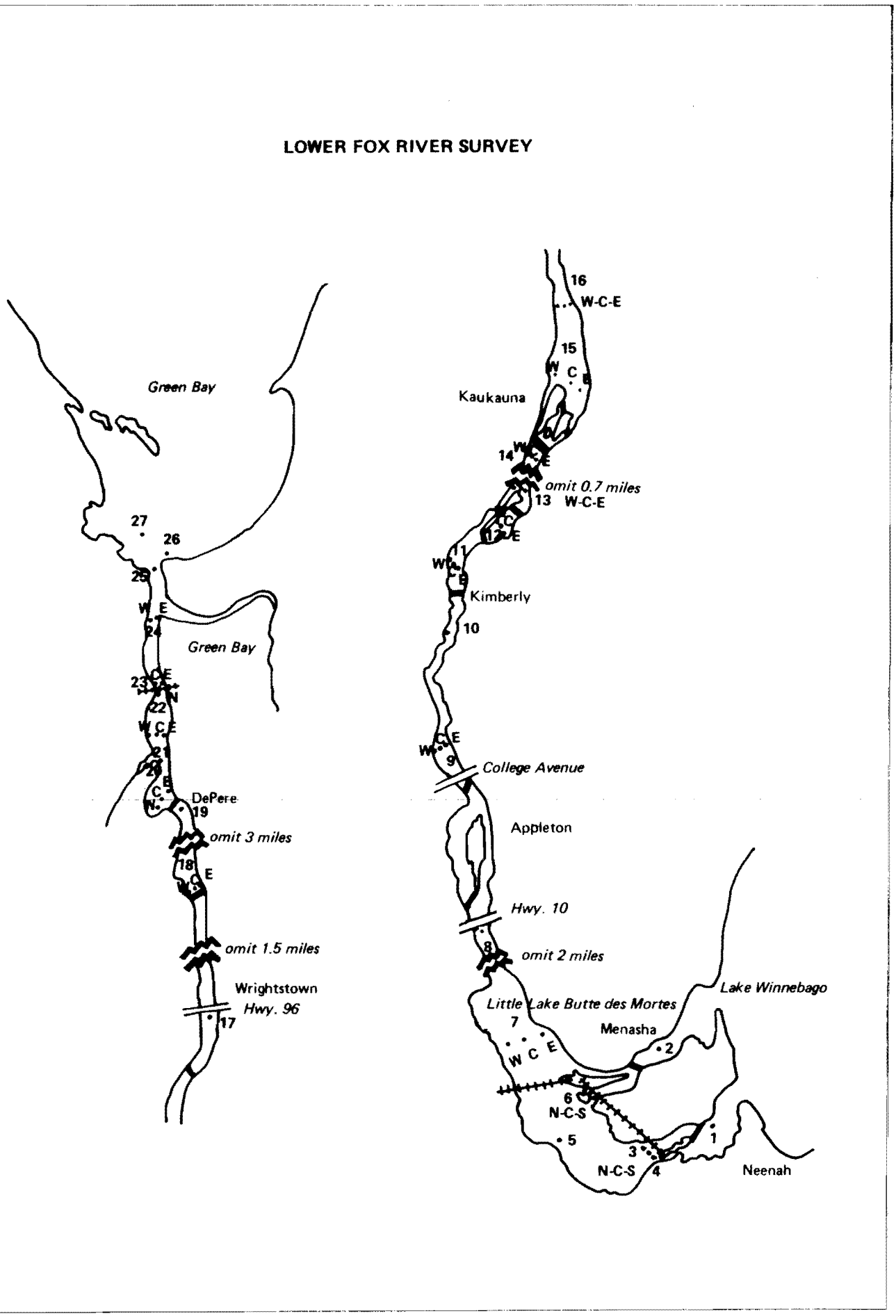


FIGURE 4. *Location of sampling stations along the Lower Fox River.*

collecting samples for a separate study in November 1976, we observed dense clouds of fibers near this station but the source could not be determined.

Transect 6 was located at the mouth of the Menasha (north) Channel, which receives cooling water effluent from American Can Company and paper processing waste from George A. Whiting Paper Company. In June sample 6n contained a total solids concentration of 2,941 ug/l dominated by paper fibers and slimes. Additional surveys indicated elevated solids concentrations but fibers and slimes were not as significant. The water at this site was grossly discolored during the June survey and observations indicated that channelized effluent from the George Whiting Paper Company was the source.

Transect 7 was established at the County Q bridge crossing Little Lake Butte des Morts. Sampling in June indicated average solids concentrations but significant fiber and slime percentages in sample 7e. The August transect indicated elevated solids concentrations and the presence of fibers and slimes. Discoloration from Bergstrom's discharge was still evident, especially on the west side of the lake. Most of the fibers settle out before reaching this point but may be flushed down stream in high flow periods.

Station 8 was established by the Highway 10 bridge in Appleton 9 km (5.6 miles) below station 3s. The only additional paper mill in this stretch is the Wisconsin Tissue Mill which was meeting BAT standards during the time of the survey. Solids concentrations were similar to upstream samples but fibers and slimes were evident in the June and January samples. This indicates that paper mill wastes are being carried in suspension from upstream sources and have a potential impact on the ecosystem for some distance. During high flow periods it is probable that the entire system can flush into Lower Green Bay.

Transect 9 was located 0.4 km (0.25 miles) below the College Avenue Bridge and Consolidated Paper Mill in Appleton. The mill discharge is located immediately below the bridge on the east side of the river. Four other paper mills are located above this site but all discharge to the Appleton sewage treatment plant located below transect 9. Paper fibers were significant seston components in all samples, and slime forming organisms were observed in all but the January samples. The January 9e sample contained 45% paper fibers and a solids concentration of 616 ug/l. A sludge bed extends from the mill discharge along the east shore for 1 km (0.6 mile).

The Appleton area is where the river reaches its maximum constant turbidity and shows little improvement to the mouth. The combination of several industrial discharges from Neenah-Menasha to Appleton appear to be the cause.

Station 10 was located at Sunset Point Park located 2.4 km (1.5 miles) downstream from the Appleton sewage treatment plant. Paper fibers and slime organisms were significant but solids were not elevated above background levels. An increase in total phosphorus and organic nitrogen was indicated. The velocity of the river at this site is low and the fibers and other suspended solids tend to settle out in this stretch. Septic sludge is evident a short distance below the sewage treatment plant and more stable sludge covers the river bed for 1.3 km (0.8 miles). Additional scattered sludge deposits are present down to the Mid Tech Dam at Kimberly.

Transect 11 was established approximately 0.4 km (0.25 mile) below the Mid Tech Paper Corporation. The mill's discharge is above the dam on the east side, and during low flow periods appears to contribute to the sludge bed located there. Seston analysis of all samples indicated significant concentrations of fibers and slimes, especially on the east side. Total solids concentrations were higher in all samples from station 11e than at station 10. Paper fibers and clumps of *Sphaerotilus* were observed floating along the east side of the river. A sludge bed is located above the Little Chute dam a short distance below Mid Tech. The Mid Tech Mill discharge appears to contribute. Station 12e, located below the Little Chute dam, was sampled in June and contained a significant percentage of fibers and slime forming organisms, and still had a high solids concentration.

Transect 13 was located below Appleton Papers in Combined Locks. This mill reportedly discharges its processing waste to the municipal sewage treatment plant, but elevated solids and a significant percentage composition of fibers and slimes in the seston indicates some waste may be entering the river. However, this site could still be influenced by the Mid Tech Mill discharge. Elevated phosphorus concentrations were also found at this location, and could be the influence of the mill, or Little Chute and Kimberly sewage treatment plants.

Samples collected from station 15 located below the Thilmany Pulp and Paper Company revealed an increase in solids in the winter sample only, but all sampling periods indicated significant concentrations of fibers and slimes. Slightly elevated ammonia and organic nitrogen concentrations were also associated with Thilmany's discharge. A sludge bed composed of fibers, wood chips and slimes extends below the mill for approximately 3.6 km (2.2 miles). Fibers and slimes in suspension were obvious below the discharge. The Thilmany mill discharge had a distinct impact on the ecology and aesthetics of this section of the river.

Between the Thilmany Paper Mill and the DePere Dam the Fox River receives effluent from only the Wrightstown sewage treatment plant and nonpoint sources. This 24.7 km (15.3 miles) stretch of river shows definite signs of recovery. Other studies indicate improved dissolved oxygen concentrations, and a sediment study in 1976 indicated the presence of live clams between Wrightstown and Little Rapids. Sample stations 16 through 19 were located from 1.6 km (1 mile) below the Thilmany Mill to just above the DePere Dam. The data indicate fairly stable solids concentrations at station 16 and 18 and then an increase at Station 19 in June and August. The increase in solids is due to greater algae production, which in this situation is an indication of improved water quality. The solids concentration in the January sample was greatly reduced at station 19 compared to samples taken above this stretch of the river. Trace amounts of paper fibers were found in most of the seston samples and a trace of slime-forming organisms was found in one sample. The effect of upstream papermill effluents is also indicated by the presence of scattered sludge beds containing wood chips and fibers. The stream through this stretch remains turbid and the periphyton appears to be dominated by slime-forming organisms.

The Nicolet Paper Mill and discharge is located directly below the DePere dam on the west shore. Transect 20 was established below the dam with station 20w located below the discharge. Samples collected 275 m below the outfall in June did not indicate relatively high concentrations of solids or significant percentages of fiber and slimes. The flow is negligible in this area and the suspended materials apparently settle out in a short distance. Succeeding samples were collected immediately below the outfall and indicated elevated solids concentrations with significant percentages of fibers and the presence of slime-forming organisms. The March sample contained a total solids concentration of 604 ug/l compared to 94 ug/l above the dam, and a fiber concentration of 40% compared to a trace above. The nutrient data indicates the Nicolet Mill also contributes significant amounts of nitrogen and higher than normal phosphorus to the river. An extensive sludge bed is located below the discharge.

The U.S. Paper Mills Company is

located a short distance below the Nicolet Paper Mill but its effluent goes to the DePere sewage treatment plant. Station 21 was established approximately 70 m below the STP but was sampled in March only. The total solids concentration at that time was 3,891 ug/l of which 55% was paper fibers and 20% was biological floc. In addition to the solids problem the concentrations of phosophorus, organic nitrogen and ammonia were extremely high. Paper fibers are usually not significant in sewage treatment plant discharges; it therefore appears that the source of fibers is the U.S. Paper Mill. A sludge bed is located along the west shore for approximately 1.6 km (1 mile) below the STP outfall.

The Fort Howard Paper Company discharge is located 3.7 km (2.3 miles) downstream from the DePere sewage treatment plant. Transect 23 was established downstream from Fort Howard's discharge. June samples were collected approximately 275 m (300 yd) below the mill and did not indicate a significant impact. The August and March samples were collected approximately 23 m (25 yd) below the discharge and sample station 23w did reveal a significant impact.

The August sample indicated an increase in solids with 13% fibers and 5% slime-forming organisms. Biological floc from Fort Howard's waste treatment system made up 15% of the sample. The March sample did not indicate a solids increase but the seston was composed of 42% fibers, 4% slime organisms and 20% biological floc. A significant increase in total phosphorus and organic nitrogen was also found.

The final three major industrial waste sources on the Fox River are located between the mouth of the East River and Green Bay. American Can Company and Charmin Paper Products Company discharge near the confluence of the Fox and East Rivers, and Green Bay Packaging discharges about half way between the mouth of the East River and Green Bay. Portions of the processing wastes of all three go to the Green Bay sewage treatment plant which discharges to Green Bay at the mouth of the Fox River. Sample stations were established just above the mouth of the East River (24), at the mouth of Fox River (25), in Green Bay just east of the STP discharge (26), and approximately 2.4 km (1.5 miles) northeast of the river mouth (27).

The only significant increase in solids was found at station 27 and was a function of zooplankton and phytoplankton productivity. A slight increase in solids was found in association with the Green Bay, STP discharge. The concentration of paper fibers and slime-forming organisms was found to be significant at station 26 in March. Chemical analysis indicated consistently high levels of ammonia nitrogen and organic nitrogen at stations 25 and 26, and elevated phosphorus concentrations at station 26.

The bottom material is dominated by sludge from the mouth of the East River to Green Bay, except in the dredged channel. An extensive sludge bed dominated by wood fibers is located north and northwest of the mouth of the Fox River, and extends into Green Bay for at least 1.6 km (1 mile).

Because of the high productivity of Lake Winnebago water feeding the Fox River, and the high nutrient concentrations found in the Fox River, it seems reasonable to expect the plankton biomass to remain high or even increase. Because of the physical characteristics of the river one would also expect to find extensive macrophyte development. What actually happens is an increase in biomass near the mouth of both Neenah and Menasha channels and then a significant decrease in biomass in Little Lake Butte des Morts extending to Wrightstown. The biomass tends to recover slightly between Wrightstown and the DePere Dam and then again decreases below DePere and stays on a downtrend to the mouth. The only significant macrophyte production is in backwater areas out of the main flow of the river for its entire length. Where macrophyte production does occur very dense stands are common.

Several factors may be responsible for the above observations but among them the most probable are toxic compounds and turbidity. In any event the decrease in biomass appears to be related to industrial and municipal discharges. It should be noted, however, that the biomass is significantly higher for a short distance below the DePere sewage treatment plant which may infer that industrial discharges may be more significant.

Chippewa River

Surveys were conducted in May and September 1976 and February 1977. Fifteen sample stations were established from the Highway 8 Bridge in Bruce to the Highway 35 Bridge at the mouth.

The main branch of the Chippewa River starts at the outlet of the Chippewa Flowage and from there to the junction of the Flambeau River receives mainly nonpoint source runoff from forest and agricultural land. Station 1 was established at Bruce in Rusk County. Total solids concentrations ranged from 39 to 166 ug/l dominated by natural organic debris. However, the organisms found in the seston were not indicative of high water quality. *Microcystis* made up a significant portion of the seston on two occasions and *Spirogyra* was significant in the August sample.

Station 2 was established above the Holcombe Dam. This station is below the junction of the Flambeau River and, in addition, the Holcombe Flowage receives drainage from the Jump River and several smaller streams. Total solids concentrations ranged from a low of 17 ug/l in February to 361 ug/l in August. These values are not high for an impoundment, but the species composition indicates eutrophic conditions. Previous observations and plankton collections for the 1974 Chippewa River Basin Report indicated solids concentrations higher than 1,000 ug/l.

Station 3 was located below the Flintkote Paper Company at Cornell. Only the August sample appeared somewhat higher than background in total solids and 15% of the sample was composed of paper fibers. Minor growths of attached slimes were noted along the shore directly below the mill indicating some nutrient input. The August sample contained plastic material which most likely came from construction work on the dam at that time. Stations 5 and 6 located 6.4 km (4 miles) and 19.2 km (12 miles) below Cornell revealed a trace of slime-forming organisms in the May sample only. This may indicate a slight influence of the mill's discharge since no other point source is located through this section.

Station 7 was located below the Chippewa Falls sewage treatment plant at the U.S. Geological Gaging Station. This station was sampled in May and February and low solids concentrations were found on both occasions. However, the organisms found in the seston indicated nutrient enrichment. Ostracods accounted for 24% of the May sample and are generally considered indicators of organic enrichment. Significantly higher nutrient concentrations were also found in both the May and February samples.

Stations 9-12 were established below the Brown Company Paper Mill in Eau Claire. Seston analysis for three sampling periods revealed elevated solids concentrations, and significant percentages of paper fibers and slime-forming organisms. Slimes were extremely abundant in August with very large "clumps" observed in suspension. The total solids concentrations and percent composition of slimes would have been higher if the slimes had not accumulated on the pump intake. Attached slimes were also noted along the east shore. The above conditions were found to extend down to station 12 at

the Interstate 94 Bridge southwest of Eau Claire.

Station 13 was established at the County H Bridge approximately 16 km (10 miles) below station 12. The only point discharge in this stretch is the Eau Claire sewage treatment plant which enters the river a short distance below the I-94 bridge. Samples taken in May and August indicated slightly reduced solids concentrations compared to the upstream stations. However, nutrient concentrations appeared to be significantly elevated to indicate more than nonpoint source infiltration and organisms collected in the seston tended to indicate enriched conditions. Patches of floating decayed organic material were noted on both visits.

Station 14 was located at Durand and station 15 was located at the State Highway 35 Bridge near the mouth of the river. Solids concentrations were consistently high at these stations ranging from 350 to 3,159 ug/l and, in addition, the nutrient concentrations were elevated and planktonic organisms were indicative of eutrophic conditions. The chemical and biological data is typical of a large stream receiving excessive infiltration from point and diffuse sources.

Flambeau River

Three surveys covering 12 sample stations from above Park Falls to the Thornapple Dam were conducted on the Flambeau River. The Flambeau River is located in northwestern Wisconsin and receives effluent from two paper mills.

Station 1 was established above Park Falls and is above any major waste source. Both the chemical and biological data indicated fair water quality although a minor bloom of *Microcystis* and *Melosira* was observed during the August survey. These organisms are generally considered indicators of eutrophic conditions.

Station 2 was located below the Flambeau Paper Company in Park Falls. This site was sampled in August and February and was found to be extremely polluted on both occasions. Total solids concentrations were 3,398 and 1,267 ug/l, respectively, and the composition of paper fibers was estimated to be 72 and 99%. A trace of slime-forming organisms was found in both seston samples. The periphyton in this area was dominated by slimes and the river bottom was covered by a dense layer of fibrous sludge and wood chips.

Station 3 was established at the Highway 13 Bridge which is abut 2.4 km (1.5 miles) downstream from the paper mill. The solids concentration was low in June and February but was 1,774 ug/l in August. Paper fibers and slimes were significant in all samples. The composition of the February seston sample was estimated to be 91% slime-forming organisms. The bottom of the entire impoundment is covered by sludge and wood chips. Anaerobic gas evolution was causing upwelling and resuspension of settled fibers and wood chips during all surveys. A heavy growth of *Sphaerotilus* was also noted on natural substrates and the dam.

Station 4 was located 2.4 km (1.5 miles) below Station 3 at the County Hwy. 13 bridge. A high composition of fibers and slimes, both in suspension and attached, was evident although the solids concentration was significantly reduced. The bottom was still covered by anaerobic sludge and wood chips.

Paper fibers were found in the seston to station 5 at the Pixley Dam which is about 9.7 km (6 miles) below the Flambeau Paper Mill. Total solids concentrations were near station 1 values at this point but the physical and biological impact of the discharge was evident. The bottom was still covered by sludge and wood chips and the periphyton was dominated by *Sphaerotilus* and *Cladophora*. The presence of *Cladophora* at this point probably indicates partial stream recovery. Significant percentages of slimes persisted in the seston samples as far as station 7 at Nine Mile Creek, about 21 km (13 miles) below the mill. Macrophyte growth was abundant at this station indicating water quality recovery. Station 10 was located at Big Falls Dam and all parameters indicated good water quality.

The Brown Company Absorbent Products Division Mill discharges to the Flambeau River in Ladysmith. Samples collected 0.8 km (0.5 mile) below the mill in June and February did not indicate nuisance conditions. However, the organisms identified in the seston did indicate some organic contribution.

The final station on the Flambeau was located at the Thornapple Dam where we found conditions similar to Station 1.

Wolf River

The Wolf River is located in northeastern Wisconsin, and is one of the best known and most heavily used recreational rivers in the state. This river was included in the study because of its recreational quality and because it receives effluent from one paper mill at Shawano. Samples were collected from 7 stations located between Langlade and New London.

Station 1 was established near Langlade and station 2 was established at Keshena. The watershed to this point is a combination of agricultural and forested land and may receive some drainage from septic systems. The chemical and biological data indicate good water quality. Total solids concentrations were higher than expected (226 to 393 ug/l), but were composed of 90% natural organic debris which may be expected from a forested watershed.

Station 3 was established 90 m (100 yd) below the Shawano Paper Mill. Samples collected in June and September indicated slight nutrient concentration increases, and significant solids concentration increases in the June, September and January samples. Solids concentrations ranged from 1,035 to 2,694 ug/l and the seston was dominated by paper fibers and aluminum silica particles. Aluminum silica is used as a paper whitener. The entire river bottom in this area is covered by a dense mat of fibers and aluminum silica particles. Slimes accounted for about 5% of the seston sample but did not appear to present a nuisance.

Station 4 was located at the Highway 22 Bridge 1.6 km below the mill. The solids load was decreased, but the seston was still composed of 40% fibers and 30% aluminum slica. Station 5 located about 13 km (8 miles) below the mill revealed the same relationship as station 4 except the aluminum slica particles were absent. The seston community was more diverse at Station 5 and contained fewer tolerant organisms indicating recovery.

Station 6 located at Barker Park near Shiocton revealed conditions typical of a meandering stream flowing through an agricultural and marshy watershed. Total phosphorus was somewhat elevated and the relatively high solids concentration (860 ug/l) was dominated by organic debris and silt. In general, the water quality appears good at this station.

The final station on the Wolf River was established at Riverside Park in New London and exhibited characteristics of severe organic pollution. Total solids were not relatively high but the seston sample contained a significant percentage of slimes and the periphyton was dominated by extensive slime growths. An increased number of tolerant organisms was also found in the seston. The Bordon Company, located in New London, is suspected as the source of nutrients responsible for the slime production.

Menominee River

The Menominee River was included

in this study because of its recreational value and because it receives the discharge from two paper mills. A total of 10 sampling stations were established, originating above Niagara and extending to the mouth of the river.

Water quality at station 1, located at the Highway 141 Bridge near Niagara, was excellent based on chemical and biological parameters. The Niagara of Wisconsin Paper Corporation discharges to the Menominee River in Niagara and samples collected 182 m (200 yd) below the mill indicated severe degradation. Total solids concentrations ranged from 290 to 1,918 ug/l below the mill compared to 7 to 12 at station 1. The seston below the mill was composed almost entirely of paper fibers and slime-forming organisms. Abundant slime growths were noted floating on the surface and attached. Station 3 was located about 1.2 km (0.75 mile) and Station 4 was located near the Highway 8 Bridge about 8 km (5 miles) below the mill. The same conditions were found at both of these stations, with the exception that the water was not as discolored at station 4. Station 5 was located at Pemene Falls 34 km (21 miles) below Niagara. Solids concentrations were reduced, but paper fibers still made up 5 to 17% of the seston composition at this station. The appearance of a more diverse seston community indicates water quality improvement, but the forms present still indicate degradation. It is interesting to note that the periphyton community was dominated by *Cladophora* instead of slimes at this station, which is a good indicator of improved water quality in this situation.

Little change was found in water quality at the remaining stations, except for the presence of a trace to 8% paper fibers and a trace to 5% slimes below Scott Paper Company in Marinette.

Oconto River

Surveys were conducted on the Oconto River in northeastern Wisconsin to determine the impact of the Scott Paper Company discharge. Four stations were established from Oconto Falls to Stiles.

Station 1 was located above the dam and paper mill in Oconto Falls. Total solids concentrations were 22 ug/l in June and 10 in March. Other parameters also indicated good water quality. It is interesting to note that the March seston collection contained 60% mayfly larvae.

Samples collected at Station 2 directly below the Scott Paper outfall revealed total solids concentrations of 100,730 and 20,076 ug/l in January and March, respectively. Fiber concentrations were 45% in January and 99% in March. The January total solids concentration may be somewhat high because the pump sucked some material from the bottom. Slimes dominated the periphyton at this location but were not collected in the seston sample. Chemical parameters were significantly high, especially ammonia. In January an additional sample was collected near the outlet of the mill's stabilization pond, and the area was found to be extremely polluted. The solids concentration was 9,474 ug/l composed of 70% paper fibers and 20% slimes. The sample was devoid of planktonic organisms indicating toxic conditions in the pond itself. Nutrient concentrations were high, and the ammonia nitrogen concentration was 18 mg/l which is potentially toxic to fish under certain pH and temperature levels.

Station 4 was located at the Highway 141 Bridge in Stiles about 9.7 km (6 miles) below the mill. Samples were collected in June and March and were not high in volatile solids but nutrient concentrations were high and organic pollution was indicated by the organisms encountered. The June seston sample contained only 1% slime forming-organisms but the March sample contained 92% slimes. The periphyton during both sampling trips was dominated by slimes. The March seston sample contained few planktonic organisms which may indicate toxic or low dissolved oxygen conditions.

Additional samples were collected in December 1977 for evidence in a discharge permit violation hearing against Scott Paper Company. Sample 2, collected a short distance below the mill outfall, revealed 27,437 ug/l total solids composed of 99% paper fibers. Sample 3, collected below the settling lagoon, had a solids concentration of 19,219 ug/l and contained 91% fibers and 8% slimes. The rapids below the mill is covered by foam and all substrate is populated by dense growths of *Sphaerotilus*. Sample 4, collected at the 141 bridge, showed a drop in solids to 85 ug/l which again indicates that most fibers are settling out in Stiles Pond. However, the volatile solids concentration was significantly higher than above the paper mill and contained 15% fibers and 77% slimes. All available substrate was still covered by slime growths indicating that the mill is discharging very high nutrient (carbohydrate) concentrations. Station 5 was located at highway 41 in Oconto. The solids concentration was high at 289 ug/l and was composed of 3% fibers and 96% slimes. Slimes in suspension were very noticeable and the periphyton was still dominated by slimes although not as heavily as upstream samples. It is also known that a sport fishery is absent in the Oconto River from Oconto Falls to the mouth, and that an excellent sport fishery is available above Oconto Falls. The Oconto River is probably the most severely single source impacted river in the state.

Peshtigo River

Samples were collected from the Peshtigo River to assess the impact of the Badger Paper Mill effluent. Because of limited time and poor accessability most samples were collected immediately above and below the mill.

Station 1 was located about 0.4 km (0.25 mile) above the dam at Peshtigo. Samples were taken in June, September and February, and total solids were less than 30 ug/l at all times. Nutrient concentrations and the seston community were typical of the lower reaches of this type of stream.

Stations 2 and 3 were located 22.5 m (25 yd) to 180 m (200 yd) below the Badger Paper Mill discharge. It should be noted that the Badger Mill is both a pulp and paper mill and only paper processing wastes are discharged to the river. Pulp wastes are discharged to the municipal sewage treatment plant. Total solids concentrations of all samples taken from June, 1976 to February, 1977, were more than double the upstream concentrations. The concentration in September was 2,434 ug/l and consisted of 93% paper fibers. The percentage of paper fibers in other samples ranged from 9 to 35. Slimes were found in the seston samples in June and September and made up 10 and 2% of the biomass respectively. The plankton community is less diverse below the mill which also indicates stressed conditions. During the June to September surveys the periphyton was dominated by slimes and the bottom was covered by a mat of paper fibers at least 180 m below the mill. During the January and February surveys suspended wastes were not as apparent and the attached slime growths and fiber mats were gone. It appears that the impact of this discharge is quite variable, but is severe at times, probably dependent upon mill operational problems or output. Samples were not taken below the municipal sewage treatment plant but reports from the Green Bay District office indicate problems with solids which may be due to pulp mill wastes. The river may be adversely affected below the treatment plant.

Station 4 was located near the mouth of the river and was sampled in June only. All parameters were typical of a slow moving marshy stream.

The following rivers were not sampled in the previous study, but were included in this study because they are either major drainage or important recreational streams. Samples were taken in the same way as for other streams, with the exception that point source discharges were not generally taken into consideration when selecting station locations.

Badfish Creek

Badfish Creek is a small stream receiving the treated effluent from the Madison Nine Springs Sewage Treatment Plant. Routing of the effluent to Badfish Creek has always been a controversial issue. Two stations were established, one at County Trunk A and one at the Highway 59 crossing. These stations are about 14 km (8.7 miles) and 26 km (15 miles) downstream from the sewage treatment plant. Seston samples were collected from both stations in May and August, and nutrient samples were collected in August. Total solids concentrations were excessively high in all samples except Station 2 in August. The Seston was dominated by organic debris, which appeared to be biological floc, typical of sewage treatment plant effluent. Slimes accounted for 26% of the seston sample at Station 1 in August. All samples were low in planktonic organisms indicating high organic pollution or toxic conditions. Nutrient concentrations were extremely high and the concentration of ammonia nitrogen was 11.5 mg/l at both Stations 1 and 2 which could account for the lack of productivity.

Rock River

The Rock River was surveyed because it drains a major portion of Southeast Wisconsin. Most of the watershed is agricultural, although large tracts of marshland are common. The area is endemically rich in nutrients which is reflected by the high phosphorus and nitrogen concentrations in all samples. Samples were collected at 6 stations from the County O bridge below Hustisford to the first bridge crossing below Janesville. The river was at a high stage when samples were collected in April. Total solids concentrations ranged from 838 to 7,008 ug/l dominated by organic debris and silt. Zooplankton accounted for 45% of the sample at Station 5, and was due to biological production in Lake Koshkonong.

Samples collected in August revealed solids concentrations ranging from 65 to 1,574 ug/l. The seston was dominated by zooplankton in all samples with the highest concentrations found at Indianford Dam and below Janesville. Planktonic algae and the diatom *Melosira* were also significant at these stations. Retention of the river in passing through Lake Koshkonong appears to allow time for planktonic organism populations to peak, and additional nutrient input in the Janesville area appears to stimulate or maintain production. The southern portion of the Rock River, at least from Watertown, south, should be considered very eutrophic and subject to nuisance biological production. This condition is natural but is not doubt irritated by the wide variety of human induced inputs to the system.

Mississippi River

The Mississippi River was surveyed because of its recreational importance and because Minneapolis-St. Paul was bypassing raw sewage to the river when the study was initiated. Wisconsin residents were concerned about the effect of the sewage on public health and on the river ecosystem. Seston and nutrient samples were collected at nine stations from Hastings, Minnesota to the Lynxville Dam in Crawford County, Wisconsin. Total solids concentrations of samples collected in September 1976 ranged from 296 to 1,159 ug/l with the lowest concentrations at the mouth of Lake Pepin and the Lynxville Dam. The low concentration at the mouth of Lake Pepin is probably due to settling in the impoundment, and the low concentration at Lynxville is probably due to settling and the lack of a major input for several miles. The nutrient concentrations tend to decrease from Station 1 to 9 indicating a major input from the Minneapolis-St. Paul area. The seston in September was varied in composition but zooplankton, *Microcystis*, *Melosira* and natural organic debris dominated. Species diversity increased and the number of pollution-tollerant organisms tended to decrease from Station 1 to 9.

Samples collected in March revealed much lower solids concentrations, but the presence of slime-forming bacteria and stalked protozoans in most samples indicated organic pollution. The slimes were composed of bacterial consortiums embedded in extracellular mucilaginous material. The variety of bacteria could not be identified without culturing and could not be cultured because the samples were preserved. The heaviest concentrations of slimes were found at Stations 1, 3, 6 and 7 indicating a source of organic waste from Minneapolis-St. Paul, Red Wing, and Winona Minnesota. The presence of slimes in the winter samples only is probably due to lack of competition for nurients at that time. It is also interesting to note that slimes have only been significant in other streams receiving paper mill or concentrated sewage effluents (Badfish Creek below Madison). This is a strong indication that the Mississippi River, bordering Minnesota, is affected by sewage treatment plant effluents. Another major seston component was natural organic debris which appeared to be associated with inputs from the St. Croix, Chippewa and Black Rivers. Other dominant components include zooplankton (cladocerans and copepods) and *Melosira*. *Rhizoclonium* accounted for 40% of the seston at station 9.

Sugar River

The Sugar River is a medium-sized stream in southcentral Wisconsn flowing through rich farm and wetland. Four stations were sampled from Paoli to Albany to characterize the seston of this type of stream. Nutrient samples were collected at all but Station 1 and indicated high phosphorus and nitrogen concentrations. An excessive nutrient input is indicated from the Belleville sewage treatment plant; however, it does not appear to create nuisance conditions. Natural organic debris accounted for 55 to 84%, and silt for 2 to 28% of the seston. Copepods made up 20% of the sample at Station 4 in May, 1976. A trace of filamentous bacteria was found below Belleville and at Albany in August indicating some organic pollution. The lack of planktonic organism production is probably related to lack of light penetration due to the organic debris and silt load.

Fox (Illinois) River

The Fox River is one of the major streams draining the southeast corner of the state, flowing through marsh, agricultural and urban areas. Samples collected above Waukesha in May and August revealed low solids concentrations dominated by natural organic debris. Nutrient concentrations were high in May and low in August indicating that nonpoint source runoff is a major nutrient source. Station 2 was located at the County H bridge 5.6 km (3.5 miles) below the City of Waukesha. The May sample indicated considerably higher total solids but reduced nutrient concentrations. The seston was again dominated by natural organic debris and silt. The reduced nutrient concentrations may be due to increased dilution from ground water

and small stream input. The August sample at Station 2 also had a higher solids concentration but was dominated by filamentous green algae. Nutrient concentrations were considerably higher than those at Station 1. The Waukesha sewage treatment plant is the probable source, although nuisance conditions were not indicated. Station 4 was located at the Highway 50 bridge in Kenosha County, and although solids concentrations were relatively high and the water appeared more turbid, nuisance biological conditions were not found. The seston was dominated by natural organic debris and silt in May, and by debris and zooplankton in August.

Black River

The Black River is a large river draining parts of West Central Wisconsin. The watershed is a combination of forested and agricultural land, and a major portion lies within the Driftless Area. The river offers recreational opportunities for fishermen and canoers. Samples taken from above Black River Falls, Melrose and the Highway 53 bridge in May indicated nutrient concentrations sufficient to produce nuisance growths of algae, although nuisance conditions were not observed. Total solids concentrations ranged from 26 to 784 ug/l dominated by natural organic debris. Silt was a major seston component at stations 2 and 3 and copepods were important at Station 1. Station 4 was located at the Highway 93 bridge near the mouth and was sampled in September and March. Solids concentrations were 124 ug/l in September and a high of 2,258 ug/l in March. The seston was again dominated by natural organic debris and silt. A wider variety of organisms was noted at this station and is probably related to generally higher nutrient concentrations and reduced velocity. Nuisance conditions were not observed and the river is considered moderately clean.

Platte River

The Platte River is a medium-sized stream draining the central part of Grant County. The stream flows through agricultural land in the Driftless Area of Wisconsin, and is highly regarded as a smallmouth bass fishery. Samples for nutrient and seston analysis were collected from three locations, two in April and one in August. Total solids concentrations ranged from 15 to 859 ug/l and nutrient concentrations were low. The seston was dominated by natural organic debris and silt in April and by natural organic debris in August. Planktonic organisms were obvious in the August sample only.

St. Croix River

A large river, the St. Croix forms part of the northwest boundary between Wisconsin and Minnesota and has a watershed dominated by forested and agricultural lands. Two samples collected from the upper portion of the river in June indicated moderate nutrient and solids concentrations. The seston was dominated by natural organic debris and silt which has proven typical of good quality streams. Samples were collected near the mouth in conjunction with the Mississippi survey in September and March. The nutrient concentrations are similar to the above stations, but the solids concentration was higher in the September sample. The seston sample revealed greater biological production dominated by zooplankton and *Microcystis* in September and zooplankton in March. The production of planktonic organisms is probably associated with the impounded waters above this site. Although the sampling is limited, the overall water quality appears to be good based on the present samples and observations.

Bois Brule River

The Bois Brule is perhaps one of the best known rivers in the State of Wisconsin. It is highly regarded for its trout fishing and canoeing quality. It is a relatively large trout stream draining a small watershed dominated by forested lands; however, the soils in this area are subject to severe erosion problems. Only one sample was collected in June at the Highway 13 bridge. The solids concentration was a moderate 446 ug/l dominated by natural organic debris and silt. The remainder of the seston was composed of 3% *Microcystis*, and a trace of *Melosira, Fragillaria* and *Closterium.* Nutrient concentrations were sufficient for plankton production, but growth is inhibited by the water temperature which seldom exceeds 16°C.

Pike River

The Pike River in northeastern Wisconsin had recreational qualities similar to the Bois Brule but is not as well known. It also drains a relatively small forested watershed, but the soil in this area is not as erosion prone. One sample was collected at the County K bridge in July. The total solids concentration was 257 ug/l composed of 80% natural organic debris and a trace of rotifers, diatoms, and algae. Twenty percent of the sample was a fine sandy silt. Nutrient concentrations were the lowest for all rivers sampled. The lack of biological production is associated with low nutrient concentrations and water temperature.

TABLE 2. *Discharges creating nuisance conditions, 1976-77.*

Waste Source	Nuisance Condition			
	Suspended Slime	Suspended Fibers	Attached Slimes	Biological Floc
Wisconsin River				
St. Regis Paper Co.	X	X	X	
Wausau Paper Mill	X	X	X	
Mosinee Paper Co.	X	X	X	
Stevens Pt. STP				X
Consolidated Papers, Whiting		X		
Consolidated Papers, Wisconsin Rapids		X	X	
*Nekoosa Papers, Pt. Edwards		X	X	
*Nekoosa Papers, Nekoosa	X	X	X	
Fox River				
Bergstrom Paper	X	X		
George A. Whiting Papers	X	X		
Consolidated Papers		X		
Midtec Paper Corp.	X	X		
Thilmany Pulp & Paper Co.	X	X		
Nicolet Paper Co.		X		
DePere STP		X		X
Fort Howard Paper Co.		X		X
Chippewa River				
Brown Co.	X	X	X	
Flambeau River				
Flambeau Paper Co.	X	X	X	
Menominee River				
Niagara Paper Corp.	X	X	X	
Oconto River				
Scott Paper Co.	X	X	X	
Peshtigo River				
*Badger Paper Mill		X	X	
Wolf River				
Shawano Paper Mill		X		
Bordon Co., New London			X	

*Following this survey the discharges of both Nekoosa Mills went to a combined treatment system and observations at the lower sampling point indicated a significant reduction in slime and fiber concentrations. The Badger Paper Mill on the Peshtigo River started discharging a portion of its waste to the municipal treatment plant and conditions also improved there.

TABLE 3. *Selected data from the 1963-65 survey**

Station No.	Location	Date	Total Solids (µg/l)	Volatile Solids (%)	Fibers (%)	Slimes (%)	Remarks
Wisconsin River							
2	Rhinelander HY 8 below mill	1963	2,394	96.5	99		Water cloudy with fibers and slime
4	Hat Rapids Dam	1963	61.56	53.5	5	90	Moderate slime growth on bottom
5	Ski Hill Road	1963	440.37	58.3	1	95	Heavy floating slime
7	Tomahawk HY 51 above mill	1963	4.47	80.7	90		
17L	Marathon - 100 yds. below	1963	134.8	92.3	95		Heavy surface foam
19A	Mosinee - 200 yds. below mill	1963	543.37	84.4	85		
21	Stevens Pt. - Bukholt Park	1963	5.43	81.9	92		No fiber foam or slime apparent
24A	Whiting - 1000 yds. below dam	1963	8.05	77.2	90		Much surface foam
25	Whiting - 5 mi. below dam	1963	157.52	93.3	99		No foam or slime apparent
28B-1	Wis. Rapids - 500 yds. below Gd. Ave. bridge	1963	133.58	95.6	90		Much foam but no apparent slime
2	Rhinelander HY 8 below mill	1965	10,764.3	94.6	90	2	Heavy fibers and oil slick on water
15	2 mi. below Brokaw	1965	1,882.6	78.0	60	15	Much floating slime
16	Lk. Wausau above mouth of Rib River	1965	263.6	89.1	50	40	*Sphaerotilus* predominant, clumps of floating slime
18	Happy Hollow	1965	171.5	84.1	65	35	Clumps of slime on rubble and debris
23	200 yds. below Consol. Paper mill at Whiting	1965	664.2	93.4	95		
27	Below mill & dam - Biron	1965	1,135.4	96.5	90		Water cloudy with fibers
32	Head of Petenwell Flow.	1965	12.2	59.1	Trace	70	*Sphaerotilus* predominant; slimes observed in water
Menominee River							
M2	200 yds. below Niagara mill - Wis. side	1963	1,740.36	83.3	100	Trace	
		1965	17,670.33	95.6	99		
M6	.5 mi. below Sturgeon Falls	1963	81.12	68.0	5	29	
		1965	38.8	67.3	15	4	
M12	300 yds. below Scott Paper - Wis. side	1963	93.31	93.3	90		
		1965	456.09	94.2	80		
M15	River mouth, lighthouse to 1st channel marker	1963	48.79	66.5	60	Trace	
		1965	50.58	78.6	40	Trace	
Oconto River							
2A	.5 mi. below mill	1963	4,360.6	92.7	80	20	Heavy *Sphaerotilus* growths in river
Peshtigo River							
P2	150 yds. below mill	1965	5,857.14	96.2	99		
P3A	.75 mi. below mill, E. side	1965	1,247.09	94.4	85	10	
P8	8.5 mi. below mill	1965	7.38	73.7	30	30	
Flambeau River		July					
2	Below Park Falls Dam	1963	120.74	82.6	95		
		Nov. 1963	101.86	65.7	15	65	*Sphaerotilus, Melosira* predominant
		July					
6	At Nine-Mile Creek	1963	65.52	85.9			Pond weeds
		Nov. 1963	153.07	79.3		Trace	Organic debris predominant
Chippewa River		July					
14	Cornell - below dam	1963	790.69	94.2	60		Wood chips floating, *Oscillatoria* sp.
		Nov. 1963	2,973.21	48.9	25		*Melosira, Oscillatoria*, large wood chips

TABLE 3. *(Cont.)*

Station No.	Location	Date	Total Solids (µg/l)	Volatile Solids (%)	Fibers (%)	Slimes (%)	Remarks
17	.25 mi. below dam in rapids at Eau Claire	July 1963	9,518.34	93.9	95		
		Nov. 1963	2,138.46	96.7	97	Trace	
		Mar. 1964	330.8	95.5	90	3	
22	100 yds. above Caryville Ferry	July 1963	42.14	73.4	Trace		Insects, variety of algae, *Aphanizomenon*
		Nov. 1963	849.78	70.9	25	60	
		Mar. 1964	568.0	66.6	20	60	*Sphaerotilus, Spriogyra,* Cladocera, Copepoda
Lower Fox River							
3S	Mouth of Neenah channel south side	July 1963	10,136		99		
		Nov. 1963	2,819		99		
		Nov. 1965	3,019		80	Trace	
5R	Mouth of Menasha channel	July 1963	1,425		10	80	Slimes attached to weeds and rubble
		Nov. 1963	1,090		2		
9C	200-300 yds. below Consolidated outfall	July 1963	626		70	3	Bark and chips, *Anabaena, Microcystis*
		Nov. 1963	789		60		Fibers, Cladocera, *Melosira*
		Nov. 1965	627		Trace	25	
14C	.5 mi. above Riverside Park Dam - Kaukauna	July 1963	385		80		Blue-green algae
		Nov. 1963	662		80		
		Nov. 1965	1,235		60	20	Slimes noted in water
16C	1.5 mi. below Thilmany	July 1963	18.0		10	Trace	Stalked protozoans, fibers
		Nov. 1963	156		7	3	*Melosira,* Cladocera, *Sphaerotilus* abundant
		Nov. 1965	377		15	5	Slimes noted in water
22L	.5 mi. below Ft. Howard, west side	July 1963	14.2		18	Trace	*Microcystis* and *Aphanizomenon*
		Nov. 1963	270		7		
		Nov. 1965	1,010		85		Water discolored by fibers
24C	Mouth of Fox R. - center	Nov. 1963	222		25		Fibers, *Spirogyra*
		Nov. 1965	147		5	5	Trace of grease balls

*From Lueschow (1966)

COMPARISON WITH THE 1966 STUDY

In order to compare the data an attempt was made to correlate the seston collection techniques. Replicate samples were collected on three occasions using the pump and clark bumpus with number 20 and number 2 mesh nets. The percent standard deviation ranged from 14 to 57 with the clark bumpus number 20 mesh net and pump number 2 mesh net exhibiting the greatest variation. In general the clark bumpus collected a greater quantity of seston per unit volume; however, we don't think the counting mechanism on the clark bumpus was measuring the volume of water correctly. There was better correlation between the seston composition and percent composition using the two techniques with number 20 mesh nets. The pump used with a number 20 mesh net collected a greater variety or organisms than the clark bumpus with a number 2 mesh net for all samples. Because of the variation between the two techniques, and even between replicate samples using the same technique, a quantitative correlation could not be developed.[4]

The 1966 study indicated that nuisance plankton conditions were observed when filamentous slimes approached 100 ug/l, and algae or solids measured several hundred micrograms per liter. It follows that a comparison could possibly be made by developing solids values which constituted a nuisance for the present study. Paper fibers and slimes were generally found together and a review of the data indicates that fiber plus slime concentrations of about 40 ug/l constituted a nuisance condition. Planktonic organisms were generally considered a nuisance when volatile solids concentrations approached 250 ug/l. A condition was considered a nuisance when suspended solids, surface scums or attached growths were aesthetically offensive, or interfered with recreational pursuits. Nuisance conditions as defined may also have a detrimental effect on stream ecology. Attempts to quantitatively correlate the surveys by this method were also unsuccessful. Correlations were finally based on physical descriptions and knowledge of past and present BOD loadings and dissolved oxygen concentrations. One of the problems with quantitative correlation was that it is possible for nuisance conditions to exist at low seston concentrations based on attached slime growth, surface scums or floating clumps of slime which are not captured. It is also possible for high seston concentrations to not constitute a nuisance based on the characteristics of the material, for instance, high concentrations of zooplankton or natural organic debris.

Waste sources contributing to the development of nuisance conditions on at least one occasion during this study are shown in Table 2.

Most of the waste sources that contributed to nuisance conditions in 1963-65 are still a problem (Table 3). The severity of the nuisance conditions conditions, however, has generally decreased. The distance below most waste sources exhibiting nuisance conditions has decreased and the fiber foam associated with many outfalls in 1963-65 has disappeared. Other factors indicating improved conditions is the absence of septic sludge beds below many sources and a general improvement in dissolved oxygen concentrations which has been documented by other studies.

The waste sources indicated in Table 4 have not shown an improvement from the previous survey and still have a severe impact on receiving streams.

TABLE 4. *Discharges showing little or no improvement since the previous study (1963-65)*

River	Waste Source
Wisconsin	Wausau Paper Mill, Brokaw Mosinee Paper Co., Mosinee
Fox	Bergstrom Paper Co., Neenah Thilmany Pulp and Paper Co., Kaukauna DePere STP
Flambeau	Flambeau Paper Co., Park Falls
Menominee	Niagara Paper Corp., Niagara*
Oconto	Scott Paper Co., Oconto Falls

*Niagara Paper Corporation's new treatment system recently went into operation and their effluent has significantly improved.

[4]It should be noted that the percent standard deviation for samples collected with the pump and number 20 mesh net was 13.8 percent compared to 49.9 percent for samples collected with the Clark bumpus and number 20 mesh net. This data indicates that pump seston collections were more relatively accurate.

SUMMARY

The paper industry requires large quantities of water, and because Wisconsin is rich in water resources, it supports one of the highest concentrations of paper mills anywhere in the country. The first pulp and paper mills were established in Wisconsin in the late 1800's and have contributed to water pollution since then. The 1966 Slime Survey of Wisconsin Rivers was published about the time most paper mill waste loadings were at a peak. The study indicated that suspended solids and slime growths were a major problem in most streams receiving paper mill effluent.

The Federal Water Pollution Control Act of 1972 (Public Law 92-500) established the "National Pollutant Discharge Elimination System" which requires each discharger to obtain a discharge permit. The allowable level of discharge is specified in each permit. P.L. 92-500 also called for the obtainment of "Best Practical Treatment" (BPT) of all wastes by July 1, 1977. Best Practical Treatment is generally considered as secondary or biological waste treatment.

The current study was conducted to determine trends in water quality since the 1966 publication. It was conducted during the time that many new waste treatment systems were under construction and some were already in operation. It is to be hoped that by the time this report is published, much of the data will no longer be current because of BPT regulations. It does point out the fact that up to that time many industrial and municipal discharges were still having a significant ecological impact. Without more stringent Federal and State discharge regulations, these effects probably would have continued. Notable exceptions are Wisconsin Tissue and the Kimberly-Clark Badger Globe Mills which have had good effluents for some time. Mills recently improving their effluent include Consolidated, Whiting; American Can, Ashland; Niagara Paper Corporation and Nekoosa Edwards. We found 22 industries still having an impact on the receiving stream. However, in most cases the impact was not as severe as in the previous study. Seven industrial and one municipal discharge were found to be as bad or worse than indicated in the previous study.

A similar study should be conducted in the next few years to document the effects of Federal and State regulatory efforts. The question of Toxic compounds in industrial discharges also needs to be studied. Low levels of organic compounds are known to be present in many industrial effluents. Streams once devoid of fish are being repopulated with the improvement in dissolved oxygen concentrations. Bioaccumulation of organic compounds such as PCBs is a potential fishery problem.

LITERATURE CITED

DONDERO, NORMAN C.

1975. The *Sphaerotilus-Leptothrix* group. Ann. Rev. Microbiol. 29:407-427.

HARRISON, M. E. AND H. HEUKELEKIAN.

1958. Stream pollution: slime infestation — literature review. J. Fed. Sewage and Indust. Wastes. Assoc. 3(10):1278-1302.

LUESCHOW, LLOYD A.

1966. An evaluation of suspended plankton loads — Chippewa River. Wis. Comm. Water Poll. 49 pp.

LUESCHOW, LLOYD A.

1966. Slime survey of Wisconsin rivers. Wis. Comm. Water Poll. 14 pp.

MCHUGH, ROBERT A.

1965. Slime growths. Bull. Ore. Health, Ore. State Bd. Health. 43 (10):1-11.

NEUSTADTER, RICHARD A.

1976. Sediment evaluations of Lower Fox River, July-Aug. 1976. Wis. Dep. Natur. Resour. 72 pp.

PALMER, MERVIN C.

1969. A composite rating of algae tolerating organic pollution. J. Phycology 5(1):78-82.

PRESCOTT, G. W.

1951. Algae of the western Great Lakes area Cranbrook Inst. Sci. Bull. 31. 946 pp.

1968. The algae: a review. Houghton Miffln Co., Boston. 436 pp.

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